7.5 Stream Morphology

7.5.1 Introduction

The form assumed by a natural stream, which includes its cross-sectional shape as well as its planform, is a function of many variables for which cause-and-effect relationships are difficult to establish. The stream may be graded or in equilibrium with respect to long time periods, which means that on the average it discharges the same amount of sediment that it receives although there may be short-term adjustments in its bedforms in response to flood flows. On the other hand, the stream reach of interest may be aggrading or degrading as a result of deposition or scour in the reach, respectively. The planform of the stream may be straight, braided, or meandering. These complexities of stream morphology can be assessed by inspecting aerial photographs and topographic maps for changes in slope, width, depth, meander form and bank erosion with time.

A qualitative assessment of the river response to proposed highway facilities is possible through a thorough knowledge of river mechanics and accumulation of engineering experience.

Equilibrium sediment load calculations can be made by a variety of techniques and compared from reach to reach to detect an imbalance in sediment inflow and outflow and thus identify an aggradation/degradation problem. The BRI-STARS model (see Section 7.7.8) is recommended as a tool. The proposed methodology to quantify the expected scour and/or sedimentation of potential problem locations should be approved by the Hydraulics and Drainage Section.

The natural stream channel will assume a geomorphological form which will be compatible with the sediment load and discharge history which it has experienced over time. To the extent that a highway structure disturbs this delicate balance by encroaching on the natural channel, the consequences of flooding, erosion and deposition can be significant and widespread. The hydraulic analysis of a proposed highway structure should include a consideration of the extent of these consequences.

7.5.2 Levels Of Assessment

The analysis and design of a stream channel will usually require an assessment of the existing channel and the potential for problems as a result of the proposed action. The detail of studies necessary should be commensurate with the risk associated with the action and with the environmental sensitivity of the stream. Observation is the best means of identifying potential locations for channel bank erosion and subsequent channel stabilization. Analytical methods for the evaluation of channel stability can be classified as either hydraulic or geomorphic, and it is important to recognize that these analytical tools should only be used to substantiate the erosion potential indicated through observation. A brief description of the three levels of assessment are as follows.

Level 1

Qualitative assessment involving the application of geomorphic concepts to identify potential problems and alternative solutions. Data needed may include historic information, current site conditions, aerial photographs, old maps and survey notes, bridge design files, maintenance records and interviews with long-time residents.

Level 2

Quantitative analysis combined with a more detailed qualitative assessment of geomorphic factors. Generally includes water surface profile and scour calculations. This level of analysis will be adequate for most locations if the problems are resolved and relationships between different factors affecting stability are adequately explained. Data needed will include Level 1 data in addition to the information needed to establish the hydrology and hydraulics of the stream.

Level 3

Complex quantitative analysis based on detailed mathematical modeling and possibly physical hydraulic modeling. Necessary only for high risk locations, extraordinarily complex problems and possibly after the fact analysis where losses and liability costs are high. This level of analysis may require professionals experienced with mathematical modeling techniques for sediment routing (see Section 7.7.8) and/or physical modeling. Data needed will require Level 1 and 2 data as well as field data on bed load and suspended load transport rates and properties of bed and bank materials such as size, shape, gradation, fall velocity, cohesion, density and angle of repose.

7.5.3 Factors That Affect Stream Stability

Factors that affect stream stability and, potentially, bridge and highway stability at stream crossings, can be classified as geomorphic factors and hydraulic factors.

Geomorphic Factors

- Stream size
- Valley setting
- Natural levees
- Sinuosity
- Width variability
- Bar development
- Bed material
- Flow habit
- Floodplains
- Apparent incision
- Channel boundaries
- Degree of braiding
- Degree of anabranching
- Tree cover on banks

Figure 7-3 depicts examples of the various geomorphic factors.

Hydraulic Factors

- Magnitude, frequency and duration of floods.
- Bed configuration.
- Resistance to flow.
- Water surface profiles.

Figure 7-4 depicts the changes in channel classification and relative stability as related to hydraulic factors.

Rapid and unexpected changes may occur in streams in response to man's activities in the watershed such as alteration of vegetative cover. Changes in perviousness can alter the hydrology of a stream, sediment yield and channel geometry. Channelization, stream channel straightening, stream levees and dikes, bridges and culverts, reservoirs and changes in land use can have major effects on stream flow, sediment transport and channel geometry and location. Knowing that man's activities can influence stream stability can help the designer anticipate some of the problems that can occur.

Natural disturbances such as floods, drought, earthquakes, landslides, and forest fires can also cause large changes in sediment load and thus major changes in the stream channel. Although difficult to plan for such disturbances, it is important to recognize that when natural disturbances do occur, it is likely that changes will also occur to the stream channel.

7.5.4 Stream Response To Change

The major complicating factors in river mechanics are: 1) the large number of interrelated variables that can simultaneously respond to natural or imposed changes in a stream system; and 2) the continual evolution of stream channel patterns, channel geometry, bars and forms of bed roughness with changing water and sediment discharge. In order to better understand the responses of a stream to the actions of man and nature, a few simple hydraulic and geomorphic concepts are presented herein.

The dependence of stream form on slope, which may be imposed independently of other stream characteristics, is illustrated schematically in Figure 7-5.

Any natural or artificial change which alters channel slope can result in modifications to the existing stream pattern. For example, a cutoff of a meander loop decreases channel sinuosity and increases channel slope. Referring to Figure 7-5, this shift in the plotting position to the right could result in a shift from a relatively tranquil, meandering pattern toward a braided pattern that varies rapidly with time, has high velocities, is subdivided by sandbars and carries relatively large quantities of sediment. Conversely, it is possible that a slight decrease in slope could change an unstable braided stream into a meandering one.

The different channel dimensions, shapes and patterns associated with different quantities of discharge and amounts of sediment load indicate that as these independent variables change, major adjustments of channel morphology can be anticipated. Further, a change in hydrology may cause changes in stream sinuosity, meander wave length, and channel width and depth. A long period of channel instability with considerable bank erosion and lateral shifting of the channel may be required for the stream to compensate for the hydrologic change.

Figure 7-6 illustrates the dependence of river form on channel slope and discharge, showing when $SQ^{0.25} \leq 0.000\,70$ in a sandbed channel, the stream will meander. Similarly, when $SQ^{0.25} \geq 0.0041$, the stream is braided.

In these equations, S is the channel slope in meters per meter (ft per ft) and Q is the mean discharge in cubic meters per second (cubic feet per second). Between these values of $SQ^{0.25}$ is the transitional range.

Many U.S. rivers plot in this zone between the limiting curves defining meandering and braided streams. If a stream is meandering but its discharge and slope border on a boundary of the transitional zone, a relatively small increase in channel slope may cause it to change, in time, to a transitional or braided stream.

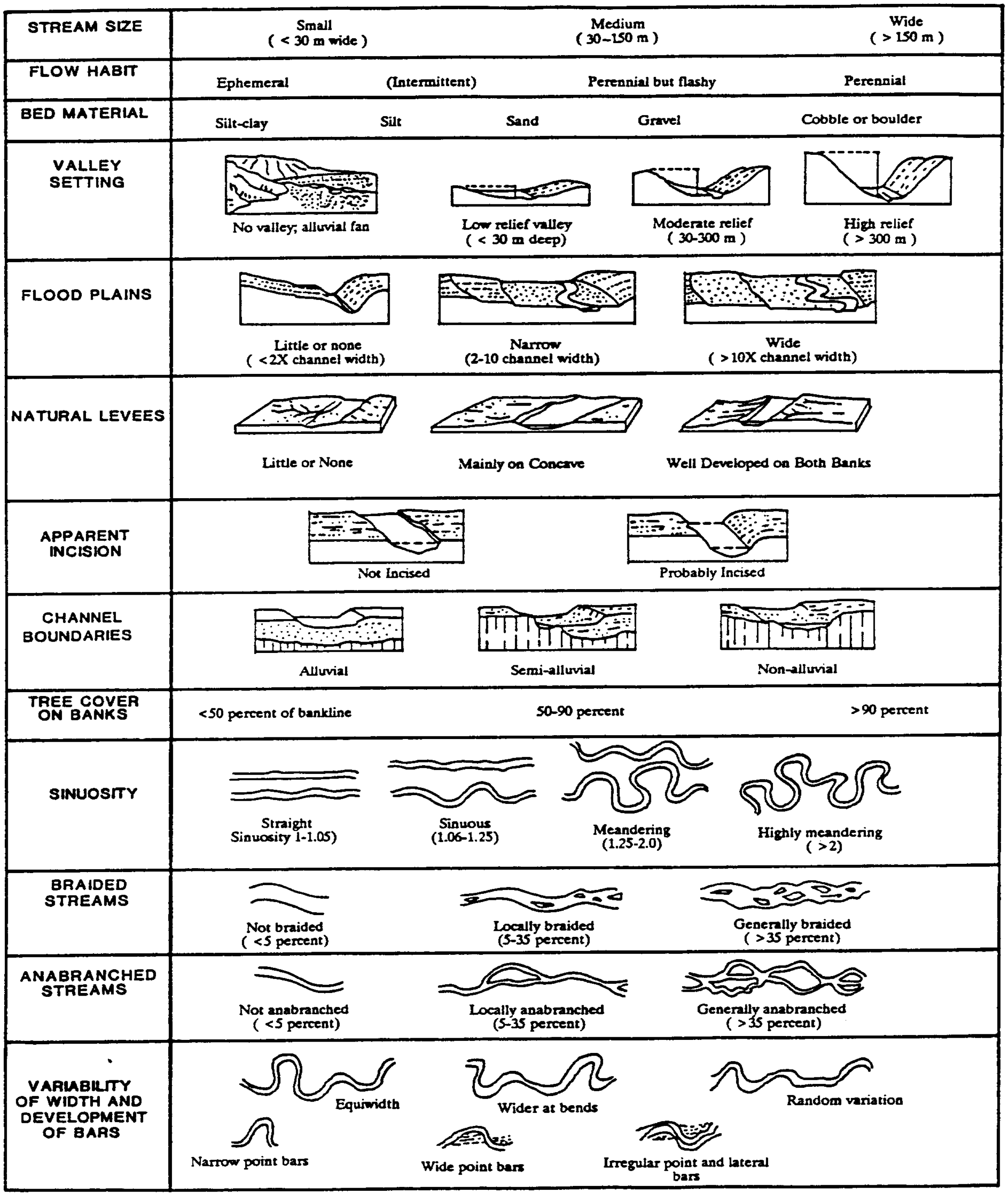

Figure 7-3 Geomorphic Factors That Affect Stream Stability

Source: Adapted From Brice and Blodgett, 1978

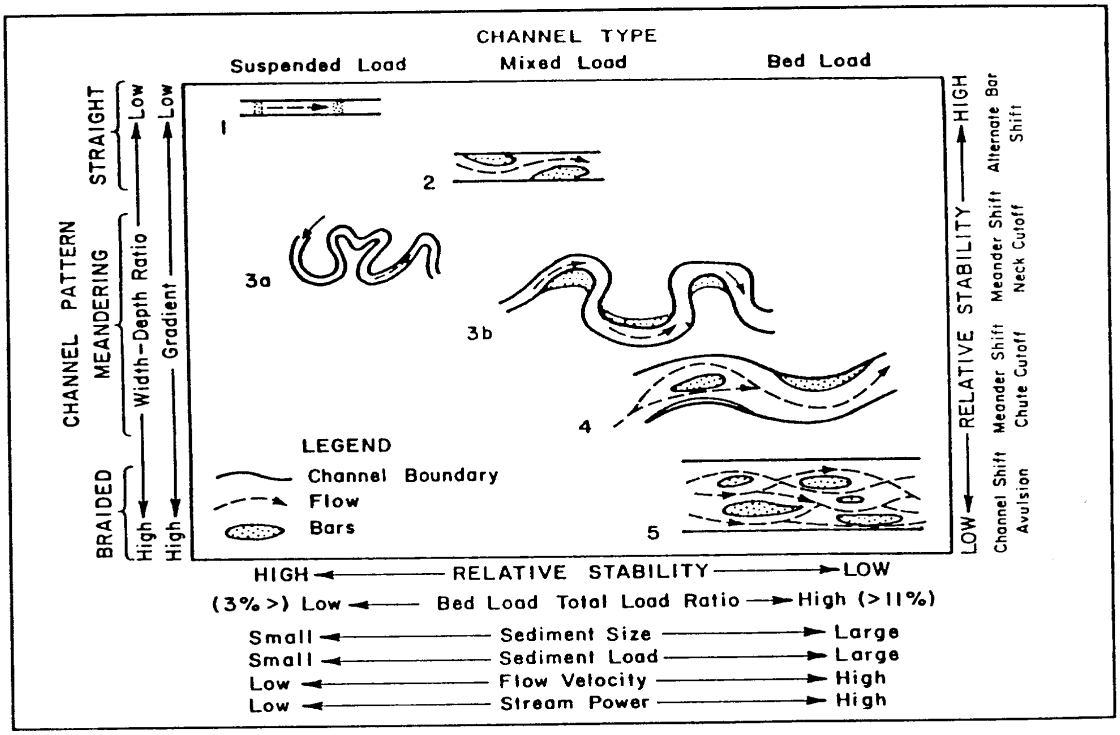

Figure 7-4 Channel Classification And Relative Stability As Hydraulic Factors Are Varied
Source: After Shen et al., 1981

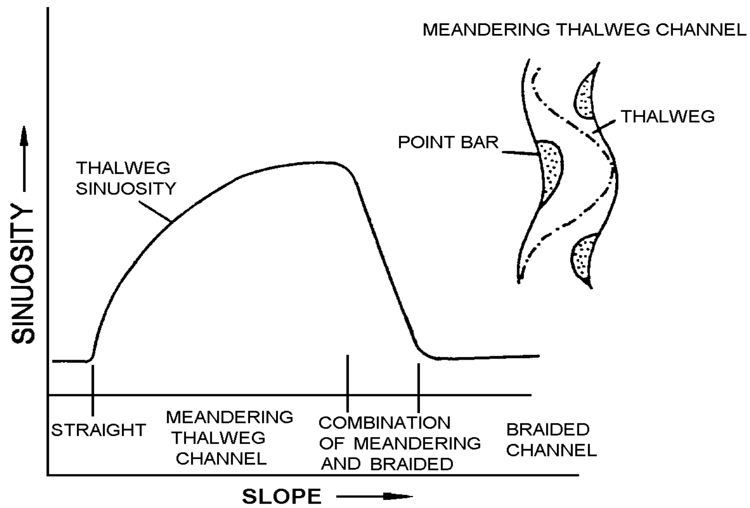

Figure 7-5 Sinuosity Versus Slope With Constant Discharge

Source: After Richardson et al., 1988

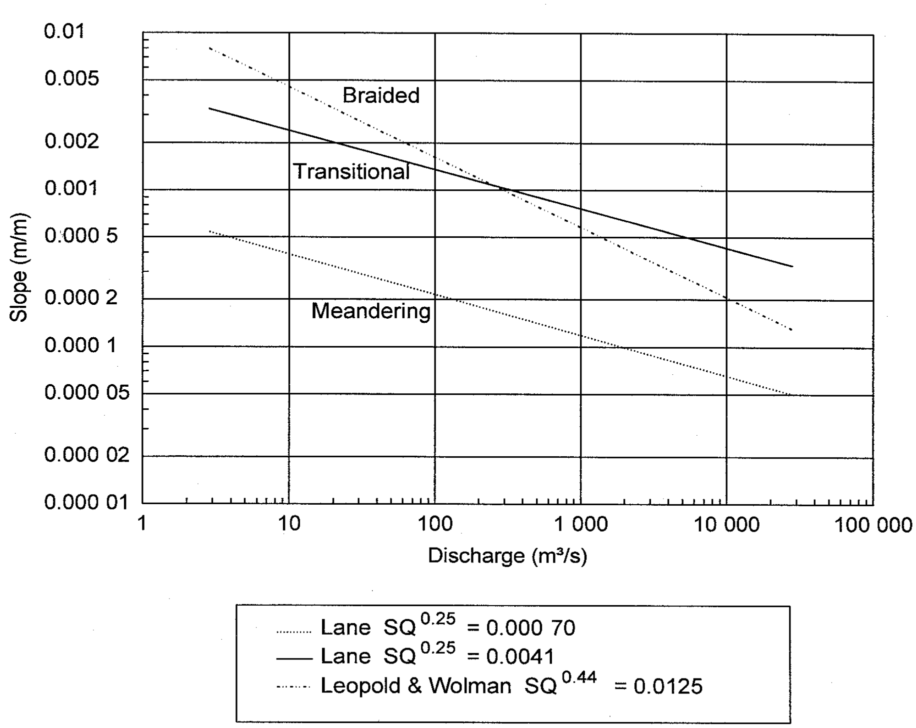

Figure 7-6 Slope-Discharge For Braiding Or Meandering Bed Streams

Source: After Lane, 1957

7.5.5 Countermeasures

A countermeasure is defined as a measure incorporated into a highway crossing of a stream to control, inhibit, change, delay, or minimize stream and bridge stability problems. They may be installed at the time of highway construction or retrofitted to resolve stability problems at existing crossings.

Retrofitting is good economics and good engineering practice in many locations because the magnitude, location and nature of potential stability problems are not always discernible at the design stage and indeed, may take a period of several years to develop.

The selection of an appropriate countermeasure for a specific bank erosion problem is dependent on factors such as the erosion mechanism, stream characteristics, construction and maintenance requirements, potential for vandalism and costs.

Below is a brief discussion of possible countermeasures for some common river stability problems.

Note: The reader is encouraged to consult with the references listed at the end of this chapter for detailed information on the design and construction of the countermeasures.

Meander Migration

The best countermeasure against meander migration is a crossing location on a relatively straight reach of stream between bends. Other countermeasures include the protection of an existing bank line, the establishment of a new flow line or alignment and the control and constriction of channel flow. Countermeasures identified for bank stabilization and bend control are bank revetments, spurs, retardance structures, longitudinal dikes, vane dikes, bulkheads and channel relocations. Measures may be used individually or a combination of two or more measures may be used to combat meander migration at a site (HEC-20, 1995).

Channel Braiding

Countermeasures used at braided streams are usually intended to confine the multiple channels to one channel. This tends to increase sediment transport capacity in the principal channel and encourage deposition in secondary channels.

The measures usually consist of dikes constructed from the limits of the multiple channels to the channel over which the bridge is constructed. Spur dikes at bridge ends used in combination with revetment on highway fill slopes, riprap on highway fill slopes only and spurs arranged in the stream channels to constrict flow to one channel have also been used successfully.

Degradation

Degradation in streams can cause the loss of bridge piers in stream channels, and piers and abutments in caving banks. A check dam, which is a low dam or weir constructed across a channel, is one of the most successful techniques for halting degradation on small to medium streams.

Longitudinal stone dikes placed at the toe of channel banks can be effective counter measures for bank caving in degrading streams. Precautions to prevent outflanking, such as tiebacks to the banks, may be necessary where installations are limited to the vicinity of the highway stream crossing. In general, channel lining alone is not a successful counter measure against degradation problems (HEC-20).

Aggradation

Current measures in use to alleviate aggradation problems at highways include channelization, bridge modification, continued maintenance, or combinations of these.

Channelization may include excavating and cleaning channels, constructing cutoffs to increase the local slope, constructing flow control structures to reduce and control of the local channel width, and constructing relief channels to improve flow capacity at the crossing. Except for relief channels, these measures are intended to increase the sediment transport capacity of the channel, thus reducing or eliminating problems with aggradation.

Another technique which shows promise is the submerged vane technique developed by the University of Iowa. The studies suggest that the submerged vane structure may be an effective, economic, low-maintenance, and environmentally acceptable sediment-control structure with a wide range of applications (HEC-20, Odgaard and others, 1986).